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EFFECT OF TEMPERATURE ON PLASTICITY AND RESISTANCE TO DEFORMATION OF COMMERCIAL TITANIUM

[Comment: The following is a translation of an article by Ye. M. Savitskiy and M. A. Tylkina which was submitted 11 February 1955 and appeared in Izvestiya Akademii Nauk SSSR, Otdeleniye Tekhnicheskikh Nauk, No 4, Moscow, April 1955, pp. 53-57.

Numbers in parentheses refer to the author' bibliography appended. Figures referred to in the text are appended to the report.]

The mechanical properties of titanium are greatly affected by the method of its derivation and its consequent degree of purity. (1. 2) The effect of carbon upon the plasticity of smelted titanium has been studied. (3, 4) This article reports the results of our 1951 investigations on the effect of temperature upon the plasticity and resistance to deformation of magneothermic commercial titanium of two grades: metalloceramic carbon-free and remelted carburized titanium. The first grade consisted of sintered titanium briguets 20 x 20 x 100 mm containing 0.2% Si. 0.11% Fe, 0.1% Cu and 0.1% Mg. These briquets were subjected to extrusion at 900 degrees through a die with a 64% reduction in area. The properties of cast titanium contaminated with carbon (to 0.5-0.8%) during smelting in graphite crucibles were studied in specimens cut from hot forged rods.

Prior to testing the specimens were subjected to diffusion annealing in vacuumed quartz ampules at 850 degrees for 3 hours.

To determine flow pressure of carbon-free titanium, extrusion was conducted in the temperature range of 600-1050 degree on specimens 20 mm in diameter and 35 mm in height with a reduction in area of 64%. The flow pressure of titanium (Fig 1) drops as the extrusion temperature is increased. The flow pressure of titanium, which is equal to 82 kg/sq mm at 620 degrees, drops to 29.3 kg/sq mm at 900 degrees and reaches 8 kg/sq mm at 1050 degrees.

In depicting this data in semilogarithmic coordinates the temperature of the polymorphous transformation of titanium becomes ~ 880 deg. The temperature coefficient of flow pressure of β-phase titanium is 3.8×10^{-3} and is greater than the temperature coefficient of the α-phase, which is 1.6×10^{-3}, which indicates the great tendency of β-titanium toward softening.

On microsections of titanium containing carbon there is observed the separation of titanium carbide in the form of separate inclusions, the quantity and size of which considerable increase as the carbon content in the titanium is increased: this is clearly shown in the unetched sections. (Fig 2a)

Annealing at 850 deg (Fig 2б,в,г) results in the formation of a polyhedral structure of α-phase Ti in all three specimens of titanium with a somewhat coarser granular structure in the carbon-free titanium.

Hardness was determined by the introduction of a Pobedit cone in a temperature range of from 20 to 1,100 deg on cylindrical specimens 15 mm in diameter.

From Fig 3 it is seen that carbon increases titanium hardness, especially at comparitively low temperatures. At 20 deg the hardness of carbon-free

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titanium is equal to 244 kg/sq mm, whereas in titanium contaminated with carbon it is 333 kg/sq mm. Increasing the carbon content from 0.53 to 0.82% does not increase hardness. As the temperature is increased a decrease in the hardness of all grades of titanium is observed. The variation in hardness is maintained up to about 600 deg; above this temperature the hardness of all three specimens of titanium is practically identical and at 700 deg is equal to 77-80 kg/sq mm, while at 1,000-1,100 deg it is 5-10 kg/sq mm.

The effect of temperature upon tensile properties was studied in temperature intervals of 20 to 1,100 deg on specimens with threaded 5-mm-diameter heads and 25-mm long gage lengths. Tests were conducted in air. The test results (Fig 4) show that as temperature is increased the tensile strength σ_B decreases while the plasticity increases in all three titanium specimens. The plasticity is especially increased after polymorphous transformation in titanium. Up to 600 deg, titanium containing carbon has greater strength than carbon-free titanium.

In heating to 400 deg a more intensive decrease in strength is observed in carbon-free titanium.

At 600 deg the tensile strengths σ_B of all three specimens are about even (6.5-10.4 kg/sq mm) and drop to 0.5-2 kg/sq mm at 1,000- 1,100 deg.

Consequently the reduction of cross sectional area ψ has a greater increase in carbon-free titanium, reaching 51% at 400 deg as against 35.7-45.4% for titanium containing carbon. Above 700 deg the reduction of cross sectional area in all three specimens reaches 90-98%. The elongation δ also increases with temperature and reaches a maximum value of 92% in carbon-free titanium at 800 deg. In titanium containing carbon, maximum elongation of approximately 95-75% occurs at 700 deg. Further temperature increase leads to a decrease in elongation apparently because the granular boundaries are damaged by the oxidation.

The results of the tests on the effect of carbon upon the tensile characteristics of titanium at various temperatures concur with the data of L. N. Sokolov, V. P. Yelyutin, and V. I. Zalesskiy. (3)

Cylindrical specimens 10 mm in diameter were tested for compression on a 35-ton hydraulic press. The rate of speed of the press was 100 mm/min.

The presence of carbon causes an increase in compressive strength at 20 deg from 159 kg/sq mm for carbon-free titanium to 254-242 kg/sq mm for titanium with an 0.53-0.82% carbon content. The maximum permissible shrinkage at 20 deg was 30% for carbon-free titanium and 15% for titanium with an 0.82% carbon content.

To compute the capacity of pressure working equipment, the value of the true stress necessary for deforming the metal is of great consequence. Compression is the principal deformation of the basic types of pressure working (pressing, rolling, forging).

To determine the value of the true stresses in the deformed metal, a series of tests were conducted in shrinking carbon-free titanium and titanium with an 0.82% carbon content at various temperatures while recording the working diagrams. From the resultant diagrams the computation of true stress (σ_{comp} kg/sq mm) was made, which determined the relationship of load at a given moment of deformation to the true cross sectional area of the specimen in the same moment of deformation. The value of the load was taken from the working diagram while

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the cross sectional area of the specimen at any moment of deformation was computed on the basis of the law of constant volume during deformation.

Figures 5 and 6 show the data obtained for temperatures 20, 400, [illegible] and 1,000 deg in the form of volumetric diagrams of true stress.

At temperatures up to 600 deg, in reducing titanium containing 0.5-0.8% carbon to a particular degree of deformation it is necessary to apply over twice the true stress required by carbon-free titanium. For example, to reduce the area of carbon-free titanium by 10% at room temperature a stress of 68.6 kg/sq mm is necessary, while for titanium with 0.82% carbon, 138 kg/sq mm is required.

To reduce carbon-free titanium by 50% at 600 deg a stress of 61 kg/sq mm is required whereas the same reduction of titanium with 0.82% carbon is attained with a stress of 132.5 kg/sq mm.

At temperatures over 700 deg both grades of titanium are easily deformed by comparatively small and nearly equal stresses. This is apparently due to the initiation of recrystallization in the deformation process. As the temperature is further increased the titanium becomes very plastic and has very little resistance toward deformation due to the appearance of the cubic β-phase. (5) [sic]

Conclusions

The plasticity and resistance to deformation at various temperatures and various stresses of commercial carbon-free titanium and titanium with 0.5-0.8% carbon have been experimentally determined. The presence of carbon within these limits increases strength and decreases plasticity at temperatures from 20 to 600 deg. The presence of carbon does not decrease the plasticity of titanium at high temperatures of 700-800 deg and more and permits hot deformation at low stresses.

Hardly any differences were observed in the properties of titanium contaminated with carbon in amounts of 0.53 to 0.82%.

[Appended figures follow:]

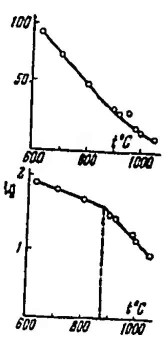

Fig 1. Effect of Temperature on Flow Pressure k in kg/sq mm of Carbon-Free Titanium

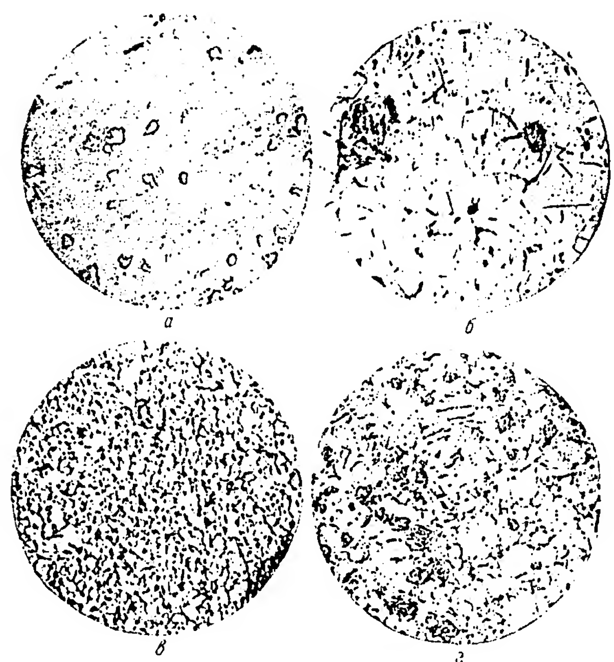

Fig 2. Microsections of Titanium X 250: a -- Titanium With 0.82% Carbon, Unetched; б -- Carbon-Free Annealed Titanium, Etched в -- Titanium With 0.53% Carbon, Annealed and Etched; г -- Titanium With 0.82% Carbon, Annealed and Etched

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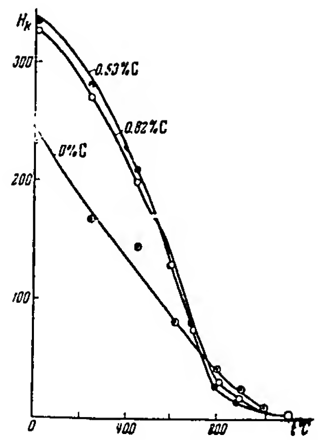

Fi[illegible]. Effect of Temperature on the Hardness of Titanium (H_k in kg/sq mm)

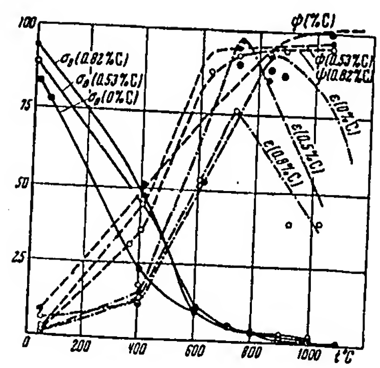

Fig 4. Effect of Temperature on Tensile Strength σ, kg/sq mm, on Reduction in Area ψ,% and on Elongation ε,% of a Specimen of Titanium Under Tension

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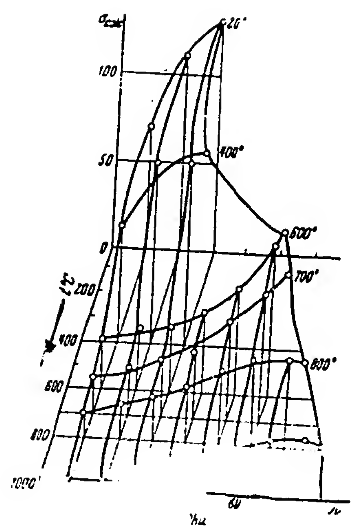

Fig 5. Volumetric Diagram of True Stress in the Compression of Carbon-Free Titanium in Relationship to Temperature and Degree of Reduction [illegible]

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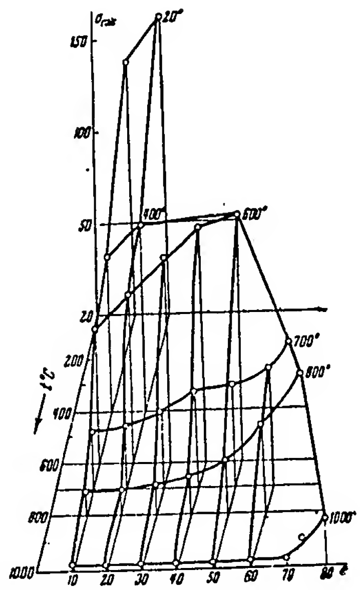

Fig 6. Volumetric Diagram of True Stress in the compression of Titanium With 0.82% Carbon, in Relationship to Temperature and Degree of Reduction

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5. [Omitted in source.]

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